

## Bound states of $\Theta^+$ in nuclei

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We study the binding energy and the width of the  $\Theta^+$  in nuclei, associated to the  $KN$  and  $K\pi N$  components. The first one leads to negligible contributions while the second one leads to a sizeable attraction, enough to bind the  $\Theta^+$  in nuclei. Pauli blocking and binding effects on the  $KN$  decay reduce considerably the  $\Theta^+$  decay width in nuclei and medium effects associated to the  $K\pi N$  component also lead to a very small width, as a consequence of which one finds separation between the bound levels considerably larger than the width of the states.

The  $\Theta^+$  exotic resonance [ 1, 2] decays into  $KN$  and the width could be very narrow according to studies of  $KN$  and  $Kd$  interaction [ 3, 4] . However, inside the nucleus this width is considerably reduced as a consequence of Pauli blocking. An intuitive way to see this is to realize that a  $\Theta^+$  at rest gives rise to  $KN$  with a nucleon momentum of about 270 MeV/c, barely above the Fermi momentum at normal nuclear matter density. According to this, the decay would be allowed. However, as soon as the  $\Theta^+$  has some momentum one realizes, by boosting the CM variables to the frame of the moving  $\Theta^+$ , that about half of the time one has components of the  $N$  momentum smaller than the Fermi momentum and the decay width is reduced to half. This is what one sees in the quantitative study of [ 5, 6, 7], with an extra reduction with increasing binding of the  $\Theta^+$ . One also finds there that the real part associated to this decay in the nucleus is of the order of 1 MeV, in agreement with [ 8], and hence too small to produce bound states in nuclei.

The real novelty comes from the two meson cloud component. A detailed study of the contribution of the two meson cloud component to the binding energy of the antidecuplet to which the  $\Theta^+$  is assumed to belong [ 9] has been done in [ 10].

The assumptions done in [ 5] are:

1) The  $\Theta^+$  is  $J^P = \frac{1}{2}^+$  and is a member of an antidecuplet to which the  $N^*(1710)$  belongs.

2) Two SU(3) invariant Lagrangians involving the smallest number of derivatives are introduced. In one of them the two mesons are in a vector state and in the other one in a scalar state. The chosen Lagrangians are

$$\mathcal{L}_1 = ig_{10}\epsilon^{ilm}\bar{T}_{ijk}\gamma^\mu B_l^j(V_\mu)_m^k,$$

$$\mathcal{L}_2 = \frac{1}{2f}\tilde{g}_{10}\epsilon^{ilm}\bar{T}_{ijk}(\phi\cdot\phi)_l^j B_m^k,$$

with  $V_\mu$  the two-meson vector current,

$$V_\mu = \frac{1}{4f^2}(\phi\partial_\mu\phi - \partial_\mu\phi\phi),$$

and  $T_{ijl}$ ,  $B_l^j$ ,  $\phi_m^k$   $SU(3)$  tensors for the antidecuplet states, the octet of  $\frac{1}{2}^+$  baryons and the octet of  $0^-$  mesons, respectively.

The couplings are then fitted to the partial decay widths of the  $N^*(1710)$  into  $N\rho$  and  $N\pi\pi$  ( $s$ -wave,  $I = 0$ ) respectively. The resulting coupling constants are  $g_{\bar{1}0} = 0.72$  and  $\tilde{g}_{\bar{1}0} = 1.9$ . The uncertainties for these constants are quite large with the current experimental information.

3) With these Lagrangians the selfenergy of the members of the antidecuplet is evaluated and a regularizing cut off of natural order is chosen (around 800 MeV), which provides bindings of about 100-200 MeV to the members of the antidecuplet from the two meson cloud, plus a splitting of the order of 20 MeV among the different strangeness partners of the antidecuplet. This splitting is about as large as the one obtained from quark correlations in most quark models, hence its importance in a detailed study of the  $\Theta^+$ .

4) The same selfenergy is now evaluated in nuclear matter by dressing up the pion, allowing it to excite  $ph$  and  $\Delta h$ , and also the  $K$ , which is dressed with the selfenergy provided by Chiral Perturbation Theory. Diagrammatically it can be seen in Fig. 1.

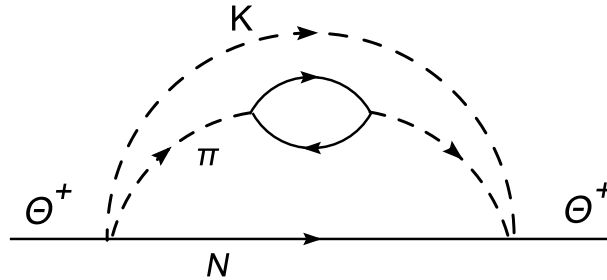


Figure 1. Selfenergy diagram due to the two meson cloud.

The results for the real and the imaginary parts can be seen in Fig. 2

What we can see in the figure is that for reasonable cut offs of the order of 700 to 800 MeV one gets an attraction in the medium which is about 60 to 120 MeV at normal nuclear matter density. Similarly large attractive potentials are found within several quark models in [ 11, 12]. We can also see in Fig. 2 the imaginary part of the  $\Theta^+$  selfenergy, which is cut off independent, and is very small. For binding energies of the order of 20 MeV it is of the order of 3 MeV. This width, added to the one coming from the reduced  $KN$  decay in the medium, is sufficiently small to have peaks of the  $\Theta^+$  bound states

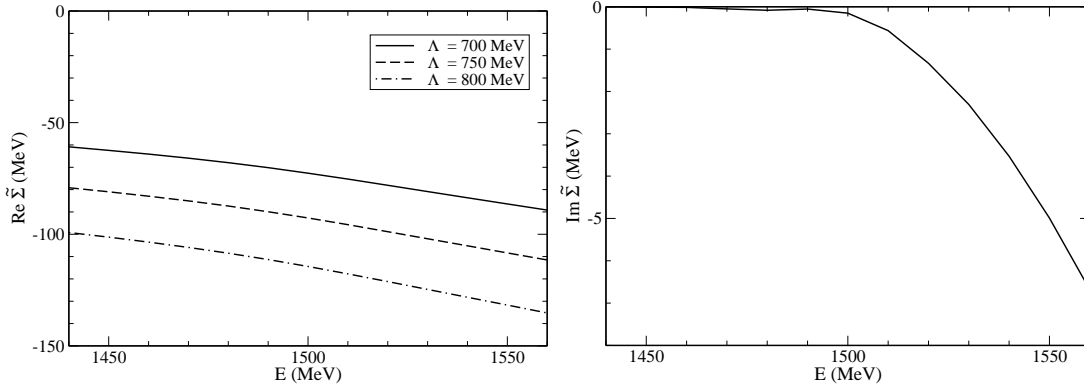


Figure 2.  $\Theta^+$  selfenergy in the medium for  $\rho = \rho_0$ .

$V = -60 \text{ MeV } \rho/\rho_0$		$V = -120 \text{ MeV } \rho/\rho_0$	
$E_i \text{ (MeV), } ^{12}\text{C}$	$E_i \text{ (MeV), } ^{40}\text{Ca}$	$E_i \text{ (MeV), } ^{12}\text{C}$	$E_i \text{ (MeV), } ^{40}\text{Ca}$
-34.0 (1s)	-42.6 (1s)	-87.3 (1s)	-98.2 (1s)
-14.6 (1p)	-30.9 (1p)	-59.5 (1p)	-83.3 (1p)
-0.3 (2s)	-18.7 (1d)	-32.0 (2s)	-67.5 (1d)
	-17.9 (2s)	-31.9 (1d)	-65.9 (2s)
	-6.3 (1f)	-8.6 (2p)	-50.8 (1f)
	-5.6 (2p)	-5.6 (1f)	-48.5 (2p)
			-33.5 (1g)
			...

Table 1

Binding energies of the  $\Theta^+$  states for two different  $\Theta^+$  potentials.

perfectly identifiable. This is seen in Table 1.

As one can see, for a reasonable potential of  $60\rho/\rho_0 \text{ MeV}$ , similar to the one of the nucleons, both in nuclei like  $^{12}\text{C}$  or  $^{40}\text{Ca}$ , the states are separated by an energy fairly larger than the width that we have calculated before. This would make a case for clear experimental observation. Suggestions for experiments have been done using the  $(K, \pi)$  reaction in nuclei [13] and there are plans to make the experiment at KEK [14].

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